

**WHAT IS CLAIMED IS:**

1. In a digital communication system, a method for communicating comprising the steps of:
  - transmitting signals from one or more transmitter antenna elements;
  - receiving said signals from via a plurality of receiver antenna elements;
  - wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein
  - at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between spatial directions employed for communication at a common frequency.
2. The method of claim 1 wherein a channel coupling said plurality of transmitter antenna elements and receiver antenna elements at said common frequency is characterized by a spatial channel matrix having a rank greater than one.
3. In a digital communication system, a method for communicating comprising the steps of:
  - transmitting signals from one or more transmitter antenna elements;
  - receiving said signals via a plurality of receiver antenna elements;
  - wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein
  - at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between subchannels, each subchannel associated with a spatial direction and a bin of a substantially orthogonalizing procedure.
4. The method of claim 3 wherein said substantially orthogonalizing procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass filter/frequency upconverter pairs operating at spaced apart frequencies..

32  
33 5. In a digital communication system, a method for preparing a sequence of  
34 symbols for transmission via a plurality of inputs of a channel:

35 a) inputting said symbols of said sequence into a plurality of inputs  
36 corresponding to a plurality of subchannels of said channel, each subchannel corresponding to  
37 an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

38 b) for each input bin, spatially processing symbols inputted to said subchannels  
39 corresponding to said input bin, to develop a spatially processed symbol to assign to each  
40 combination of channel input and input bin of said transmitter substantially orthogonalizing  
41 procedure; and

42 c) applying, independently for each said channel input, said transmitter  
43 substantially orthogonalizing procedure to said spatially processed symbols assigned to each  
44 said channel input.

45  
46 6. The method of claim 5 wherein said b) step has the effect of making  
47 spatial directions of said subchannels into a set of orthogonal spatial dimensions.

48  
49 7. The method of claim 5 wherein said transmitter substantially  
50 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier  
51 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a  
52 wavelet transform, and processing through a plurality of bandpass filter/frequency converter  
53 pairs centered at spaced apart frequencies.

54  
55 8. The method of claim 5 further comprising the step of, after said c) step,  
56 applying a cyclic prefix processing procedure to a result of said substantially orthogonalizing  
57 procedure independently for each channel input.

58  
59 9. The method of claim 5 wherein said transmitter substantially  
60 orthogonalizing procedure is optimized to reduce interference to unintended receivers.  
61

62 10. The method of claim 5 wherein said b) step comprises, for each  
63 particular input bin, multiplying a vector comprising symbols allocated to subchannels  
64 corresponding to said input bin by a beneficial weighting matrix, elements of a result vector of  
65 said multiplying step corresponding to different channel inputs of said plurality of channel  
66 inputs.

67  
68 11. The method of claim 10 wherein said beneficial weighting matrix  
69 comprises an input singular matrix of a matrix containing values representing characteristics of  
70 said channel, said coupling said plurality of channel inputs to one or more channel outputs.

71  
72 12. The method of claim 10 wherein said beneficial weighting matrix is  
73 obtained from a matrix containing values representing characteristics of a channel coupling  
74 said plurality of channel inputs to one or more channel outputs.

75  
76 13. The method of claim 10 wherein said beneficial weighting matrix is  
77 chosen to reduce interference to unintended receivers.

78  
79 14. The method of claim 13 wherein said beneficial weighting matrix is  
80 chosen based upon characterization of a desired signal subspace.

81  
82 15. The method of claim 14 wherein said beneficial weighting matrix is  
83 chosen further based upon characterization of an undesired signal subspace.

84  
85 16. The method of claim 15 wherein characterizations of said desired signal  
86 subspace and said undesired signal subspace are averaged over at least one of time and  
87 frequency.

88  
89 17. The method of claim 10 wherein said b) step comprises performing said  
90 spatial processing step so as to reduce interference radiated to unintended receivers.

91 18. The method of claim 10 wherein said b) step comprises, for each input  
92 bin, allocating symbols to each combination of channel input and input bin so that there

is a one-to-one mapping between spatial direction of a particular subchannel to which a particular symbol has been allocated and channel input to which said particular symbol is allocated.

19. The method of claim 10 further comprising the step of prior to said b) step applying a coding procedure to said symbols.

20. The method of claim 19 wherein said coding procedure is applied independently for each of said subchannels.

21. The method of claim 19 wherein said coding procedure is applied independently for each group of subchannels corresponding to an input bin of said substantially orthogonalizing procedure.

22. The method of claim 19 wherein said coding procedure is applied independently for each group of subchannels corresponding to a particular spatial direction.

23. The method of claim 19 wherein said coding procedure is applied integrally across all of said subchannels.

24. The method of claim 19 wherein said coding procedure belongs to a group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding, trellis coding, turbo coding, and interleaving.

25. The method of claim 19 wherein said coding procedure comprises a trellis coding procedure.

26. The method of claim 25 wherein a code design of said trellis coding procedure is based on one of: improved bit error performance in interference channels, a periodic product distance metric, exhaustive code polynomial search for favorable bit error rate polynomial searches, combined weighting of product distance and Euclidean distance,

product distance of multiple Euclidean distances over short code segments or over a multi-dimensional symbol, and sum of product distances over short code segments.

27. The method of claim 25 wherein a code design of said trellis coding procedure is optimized for performance in a fading matrix channel.

28. The method of claim 19 wherein said coding procedure comprises a one-dimensional trellis coding procedure followed by an interleaving procedure with sequential groups of symbols output by said trellis coding having their internal order maintained by said interleaving procedure.

29. The method of claim 19 wherein said coding procedure comprises a multi-dimensional trellis coding procedure followed by an interleaving procedure with groups of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding procedure having their internal order maintained by said interleaving procedure.

30. The method of claim 10 wherein bit loading and power are allocated to each subchannel.

31. The method of claim 10 further comprising the step of retransmitting symbols by repeating at least one of said a), b), and c) steps upon receipt of a notification that said symbols to be retransmitted have been incorrectly received.

32. The method of claim 10 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a corresponding plurality of transmitter antenna elements

33. The method of claim 32 wherein said plurality of transmitter antenna elements are co-located.

154 34. The method of claim 32 wherein said plurality of transmitters are at  
155 disparate locations.

156  
157 35. A method of processing a sequence of symbols received via a plurality of  
158 outputs of a channel, said method comprising the steps of:

159 a) applying a receiver substantially orthogonalizing procedure to said sequence  
160 of symbols, said procedure being applied independently for each of said plurality of channel  
161 outputs, each output symbol of said receiver substantially orthogonalizing procedure  
162 corresponding to a particular output bin and a particular one of said channel outputs; and

163 b) for each output bin, spatially processing symbols corresponding to said  
164 output bin to develop spatially processed symbols assigned to a plurality of spatial directions,  
165 each combination of spatial direction and output bin specifying one of a plurality of  
166 subchannels.

167  
168 36. The method of claim 35 wherein said b) step has the effect of making  
169 said plurality of spatial directions into a set of orthogonal spatial dimensions.

170  
171 37. The method of claim 35 wherein said receiver substantially  
172 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier  
173 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a  
174 wavelet transform, and processing through a plurality of bandpass filter/frequency converter  
175 pairs centered at spaced apart frequencies.

176  
177 38. The method of claim 35 further comprising the step of, prior to said a)  
178 step, applying a cyclic prefix removal procedure to said sequence of symbols independently  
179 for each of said channel outputs.

180  
181 39. The method of claim 35 wherein said receiver substantially  
182 orthogonalizing procedure is optimized to reduce deleterious effects of interference from  
183 undesired co-channel transmitters.

184

185           40.    The method of claim 35 wherein said b) step comprises, for each  
186 particular output bin, multiplying a vector comprising symbols of said output bin by a  
187 beneficial weighting matrix, elements of a result vector of said multiplying step corresponding  
188 to different spatial directions.

189  
190           41.    The method of claim 40 wherein said beneficial weighting matrix  
191 comprises an output singular vector of a matrix containing values representing characteristics  
192 of said channel, said channel coupling one or more channel inputs to said plurality of channel  
193 outputs.

194  
195           42.    The method of claim 40 wherein said beneficial weighting matrix is  
196 chosen to minimize deleterious effects of interference from undesired transmitters.

197  
198           43.    The method of claim 42 wherein said beneficial weighting matrix is  
199 chosen based upon characterization of a desired signal subspace.

200  
201           44.    The method of claim 43 wherein said beneficial weighting matrix is  
202 chosen further based upon characterization of an undesired signal subspace.

203  
204           45.    The method of claim 44 wherein said characterizations of said desired  
205 signal subspace and said undesired signal subspace are averaged over at least one of time and  
206 frequency.

207  
208           46.    The method of claim 40 wherein said beneficial weighting matrix is  
209 obtained from a matrix containing values representing characteristics of said channel, said  
210 channel coupling one or more channel inputs and said plurality of channel outputs.

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212           47.    The method of claim 46 wherein said beneficial weighting matrix is  
213 obtained by an MMSE procedure.

214

215 48. The method of claim 35 further comprising the step of after said b) step  
216 applying a decoding procedure to said symbols.

217  
218 49. The method of claim 48 wherein said decoding procedure is applied  
219 independently for each of said plurality of subchannels.

220  
221 50. The method of claim 48 wherein said decoding procedure is applied  
222 independently for each group of subchannels corresponding to an output bin of said  
223 substantially orthogonalizing procedure.

224  
225 51. The method of claim 48 wherein said decoding procedure is applied  
226 independently for each group of subchannels corresponding to a spatial direction.

227  
228 52. The method of claim 48 wherein said decoding procedure is applied  
229 integrally across all of said plurality of subchannels.

230  
231 53. The method of claim 48 wherein said decoding procedure belongs to a  
232 group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-  
233 interleaving.

234  
235 54. The method of claim 48 wherein said decoding procedure comprises a  
236 code sequence detection procedure to decode a trellis code, or convolutional code.

237  
238 55. The method of claim 54 wherein said code sequence detection procedure  
239 employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean  
240 metric, and Hamming metric.

241  
242 56. The method of claim 48 wherein said decoding procedure reduces  
243 deleterious effects of interference from undesired transmitters.

244  
245 57. The method of claim 35 further comprising the step of:



246 sending a retransmission request when received symbols are  
247 determined to include errors.

248  
249 58. The method of claim 35 wherein said channel comprises a wireless  
250 channel and said plurality of channel outputs are coupled to a plurality of corresponding  
251 receiver antenna elements.

252  
253 59. The method of claim 35 wherein said plurality of receiver antenna  
254 elements are co-located.

255  
256 60. The method of claim 35 wherein said plurality of receiver antenna  
257 elements are at disparate locations.

258  
259 61. In a digital communication system, a method for preparing a sequence of  
260 symbols for transmission via a plurality of inputs to a channel, said method comprising the  
261 steps of:

262 selecting a weighting vector for optimal transmission;  
263 applying a transmitter substantially orthogonalizing procedure to  
264 said sequence of symbols to develop a time domain symbol sequence; and  
265 multiplying at least one symbol of said time domain symbol  
266 sequence by said weighting vector to develop a result vector, elements of said result vector  
267 corresponding to symbols to be transmitted via individual ones of said plurality of channel  
268 inputs.

269  
270 62. The method of claim 61 wherein said weighting vector comprises an  
271 element indicating delay to be applied for a particular one of said plurality of channel inputs.

272  
273 63. The method of claim 61 wherein said weighting vector is optimized to  
274 reduce interference to unintended receivers.

275

276 64. The method of claim 61 wherein said weighting vector is chosen based  
277 upon characterization of a desired signal subspace.

278  
279 65. The method of claim 64 wherein said weighting vector is chosen further  
280 based upon characterization of an undesired signal subspace.

281  
282 66. The method of claim 65 wherein said characterizations of said desired  
283 signal subspace and said undesired signal subspace are averaged over at least one of time and  
284 frequency.

285  
286 67. The method of claim 61 wherein said channel comprises a wireless  
287 channel and said plurality of channel inputs are associated with a plurality of transmitter  
288 antenna elements.  
289  
290  
291

292 68. In a digital communication system, a method for processing a plurality  
293 of symbols received via a plurality of outputs of a channel, said method comprising the steps  
294 of:

295 selecting a weighting vector for optimal reception;  
296 multiplying an input vector whose elements correspond to  
297 symbols received substantially simultaneously via a selected one of said plurality of channel  
298 outputs by said weighting vector to obtain a time domain symbol corresponding to a particular  
299 input bin of a receiver substantially orthogonalizing procedure;  
300 repeating said multiplying step for successive received symbols to  
301 obtain time domain symbols corresponding to successive input bins of said receiver  
302 substantially orthogonalizing procedure; and  
303 applying said receiver substantially orthogonalizing procedure to  
304 said obtained time domain symbols.

306 69. The method of claim 68 wherein said weighting vector comprises an  
307 element indicating delay to be applied for a particular one of said plurality of channel outputs.

309 70. The method of claim 68 wherein said weighting vector is optimized to  
310 reduce deleterious effects of interference from unintended transmitters.

312 71. The method of claim 68 wherein said weighting vector is chosen based  
313 upon characterization of a desired signal subspace.

315 72. The method of claim 71 wherein said weighting vector is chosen further  
316 based upon characterization of an undesired signal subspace.

318 73. The method of claim 72 wherein said characterizations of said desired  
319 signal subspace and said undesired signal subspace are averaged over at least one of frequency  
320 and time.

74. The method of claim 71 wherein said channel comprises a wireless channel and said plurality of channel outputs are associated with a plurality of corresponding receiver antenna elements.

75. In a digital communication system, a method of preparing symbols for transmission via a plurality of inputs of a channel, said method comprising the steps of:

directing symbols to input bins of a transmitter substantially orthogonalizing procedure so that each input bin has an allocated symbol;

for each particular input bin, spatially processing said symbol allocated to said particular input bin to develop a spatially processed symbol vector, each element of said spatially processed symbol vector being assigned to one of said channel inputs;

applying said transmitter substantially orthogonalizing procedure for a particular channel input, inputs to said substantially orthogonalizing procedure being for each input bin, a symbol of said processed symbol vector for said input bin corresponding to said particular channel input; and

repeating said applying step for each of said plurality of channel inputs.

76. The method of claim 75 further comprising the step of:  
applying a cyclic prefix processing procedure to outputs of said substantially orthogonalizing procedure independently for each particular channel input.

77. The method of claim 75 wherein said transmitter substantially orthogonalizing procedure is optimized to reduce interference to unintended receivers.

78. The method of claim 75 wherein said processing step comprises:  
multiplying said symbol allocated to said particular input bin by a beneficial weighting vector to obtain said spatially processed symbol vector.

352 79. The method of claim 78 wherein said beneficial weighting vector is an  
353 input singular vector of a matrix storing values indicative of said channel, said channel  
354 coupling said plurality of channel inputs and one or more channel outputs.

355  
356 80. The method of claim 78 wherein said beneficial weighting vector is  
357 chosen to select a beneficial spatial direction for transmission.

358  
359 81. The method of claim 80 wherein said beneficial weighting vector is  
360 chosen to reduce interference to unintended receivers.

361  
362 82. The method of claim 81 wherein said beneficial weighting vector is  
363 chosen based upon characterization of a desired signal subspace

364  
365 83. The method of claim 82 wherein said beneficial weighting vector is  
366 chosen further based upon characterization of an undesired signal subspace.

367  
368 84. The method of claim 83 wherein said characterizations of said desired  
369 signal subspace and said undesired signal subspace are averaged over at least one of time and  
370 frequency.

371  
372 85. The method of claim 75 wherein said channel comprises a wireless  
373 channel and said plurality of channel inputs are associated with a corresponding plurality of  
374 transmitter antenna elements.

375  
376 86. In a digital communication system, a method for processing symbols  
377 received by a plurality of outputs of a channel comprising the step of:  
378 applying a receiver substantially orthogonalizing procedure to symbols received  
379 via a particular one of said channel outputs;  
380 repeating said applying step for each of said channel outputs to develop a result  
381 vector for each of a plurality of output bins of said receiver substantially orthogonalizing  
382 procedure, said result vector including a result symbol for each of said channel outputs; and

for each particular output bin of said receiver substantially orthogonalizing procedure, spatially processing said result vector for said particular output bin to develop a spatially processed result symbol for said particular output bin.

87. The method of claim 86 further comprising the step of:  
prior to said applying step, applying a cyclic prefix removal procedure to symbols independently for each of said channel outputs.

88. The method of claim 86 wherein said substantially orthogonalizing procedure is optimized to reduce deleterious effects of interference from unintended transmitters.

89. The method of claim 86 wherein said spatially processing step comprises multiplying a beneficial weighting vector by said result vector to obtain said spatially processed result symbol.

90. The method of claim 88 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling one or more channel inputs and said plurality of channel outputs.

91. The method of claim 88 wherein said beneficial weighting vector is chosen to select a particular spatial direction for reception.

92. The method of claim 91 wherein said beneficial weighting vector is chosen to minimize deleterious effects of interference from unintended transmitters.

93. The method of claim 91 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace.

94. The method of claim 93 wherein said beneficial weighting vector is chosen based upon characterization of an undesired signal subspace.

414  
415 95. The method of claim 94 wherein said characterizations of said desired  
416 signal subspace and said undesired signal subspace are averaged over at least one of time and  
417 frequency.

418  
419 96. The method of claim 86 wherein said channel comprises a wireless  
420 channel and said plurality of channel outputs are associated with a corresponding plurality of  
421 channel outputs.

422  
423 97. In a digital communication system including a communication channel  
424 having one or more inputs and at least one or more outputs, a method for determining  
425 characteristics of said channel based on signals received by said one or more outputs,  
426 comprising the steps of:

427 a) receiving via said one or more channel outputs, at least  $\nu$  training symbols  
428 transmitted via a particular spatial direction of said channel,  $\nu$  being an extent in symbol  
429 periods of a duration of significant terms of an impulse response of a channel; and

430 b) applying a substantially orthogonalizing procedure to said received at least  
431  $\nu$  training symbols to obtain a time domain response for said spatial direction; and

432 c) applying an inverse of said substantially orthogonalizing procedure to a zero-  
433 padded version of said time domain response to obtain a frequency response for said particular  
434 spatial direction.

435  
436 98. The method of claim 97 wherein said substantially orthogonalizing  
437 procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially  
438 orthogonalizing procedure comprises a Fast Fourier Transform.

439  
440 99. The method of claim 98 wherein said a) step comprises receiving exactly  
441  $\nu$  training symbols.

442  
443 100. The method of claim 97 further comprising the step of repeating said a),  
444 b), c), and d) steps for a plurality of spatial directions.

101. The method of claim 99 wherein each of said plurality of spatial directions corresponds to transmission through one of said plurality of channel inputs exclusively.

102. The method of claim 98 wherein said  $v$  training symbols belong to a burst of  $N$  symbols and said characteristics are determined for said burst.

103. The method of claim 102 further comprising the steps of repeating said a), b), c), and d) steps for successive bursts.

104. The method of claim 103 further comprising the step of after, said b) step, smoothing said time-domain response over successive bursts.

105. The method of claim 104 wherein said smoothing step comprises Kalman filtering.

106. The method of claim 104 wherein said smoothing step comprises Wiener filtering.

107. The method of claim 97 wherein said communication channel comprises known and unknown components, wherein said effects of said known components are removed by deconvolution, and characteristics of said unknown components are determined by said a), b), c), and d) steps, thereby reducing .

108. In a digital communication system including a communication channel having one or more inputs and one or more outputs, a method for determining characteristics of said channel based on signals received via one or more channel outputs, comprising the steps of:

receiving training symbols via said channel outputs; and



475 computing characteristics of said channel based on said received  
476 training symbols and assumptions that an impulse response of said channel is substantially  
477 time-limited and that variation of said impulse response over time is continuous.

478  
479 109. In a digital communication system, a method for communicating over a  
480 channel having at least one input and at least one output, and having a plurality of either inputs  
481 or outputs, said method comprising the steps of:

482 dividing said channel into a plurality of subchannels, each  
483 subchannel corresponding to a combination of spatial direction and an input bin of a  
484 substantially orthogonalizing procedure; and

485 communicating symbols over one or more of said plurality of  
486 subchannels.

487  
488 110. In a digital communication system, a method for preparing a sequence of  
489 symbols for transmission via a plurality of inputs of a channel, comprising the steps of:

490 a) inputting said symbols of said sequence into a plurality of  
491 input corresponding to a plurality of subchannels of said channel, each subchannel  
492 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a  
493 channel input; and

494 b) applying, independently for each said channel input, said  
495 transmitter substantially orthogonalizing procedure to said symbols assigned to each said  
496 channel input.

497  
498 111. A method of processing a sequence of symbols received via a plurality of  
499 outputs of a channel, said method comprising the steps of:

500 a) applying a substantially orthogonalizing procedure to said  
501 sequence of symbols, said procedure being applied independently for each of said plurality of  
502 channel outputs, each output symbol of said substantially orthogonalizing procedure  
503 corresponding to a subchannel identified by a combination of a particular output bin and a  
504 particular one of said channel outputs; and

505 b) processing symbols in said subchannels.

506  
507 112. In a digital communication system, apparatus for communicating  
508 comprising:  
509 a transmitter that transmits signals from one or more transmitter  
510 antenna elements;  
511 a receiver that receives said signals from via a plurality of  
512 receiver antenna elements;  
513 wherein separation of radiation patterns among either said  
514 transmitter antenna elements or said receiver antenna elements is insufficient to  
515 establish completely isolated spatial directions for communication; and wherein  
516 at least one of said transmitter and said receiver comprises a  
517 processor that processes said signals to increase isolation between spatial directions employed  
518 for communication at a common frequency.  
519

520 113. The apparatus of claim 112 wherein a channel coupling said plurality of  
521 transmitter antenna elements and receiver antenna elements at said common frequency is  
522 characterized by a spatial channel matrix having a rank greater than one.  
523

524 114. In a digital communication system, apparatus for communicating  
525 comprising:  
526 a transmitter transmitting signals from one or more transmitter  
527 antenna elements;  
528 a receiver receiving said signals via a plurality of receiver  
529 antenna elements;  
530 wherein separation of radiation patterns among either said  
531 transmitter antenna elements or said receiver antenna elements is insufficient to  
532 establish completely isolated spatial directions for communication; and wherein  
533 at least one of said transmitter and said receiver comprises a  
534 processor that processes said signals to increase isolation between subchannels, each  
535 subchannel associated with a spatial direction and a bin of a substantially orthogonalizing  
536 procedure.

115. The apparatus of claim 114 wherein said substantially orthogonalizing procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass filter/frequency upconverter pairs operating at spaced apart frequencies..

116. In a digital communication system, apparatus for preparing a sequence of symbols for transmission via a plurality of inputs of a channel:

a plurality of parallel subchannel inputs receiving said symbols, said parallel subchannel inputs corresponding to a plurality of subchannels, each subchannel corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction; a spatial processor that, for each input bin, spatially processor symbols received by said subchannel inputs corresponding to said input bin, to develop a spatially processed symbol to assign to each combination of channel input and input bin of said transmitter substantially orthogonalizing procedure; and

a substantially orthogonal procedure processor system that applies, independently for each said channel input, said transmitter substantially orthogonalizing procedure to said spatially processed symbols assigned to each said channel input.

117. The apparatus of claim 116 wherein said spatial processor has the effect of making spatial directions of said subchannels into a set of orthogonal spatial dimensions.

118. The apparatus of claim 116 wherein said transmitter substantially orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a wavelet transform, and processing through a plurality of bandpass filter/frequency converter pairs centered at spaced apart frequencies.

119. The apparatus of claim 116 further comprising: a cyclic prefix processor that applies a cyclic prefix processing procedure to a result of said substantially orthogonalizing procedure independently for each channel input.

120. The apparatus of claim 116 wherein said transmitter substantially orthogonalizing procedure is optimized to reduce interference to unintended receivers.

121. The apparatus of claim 116 wherein said spatial processor comprises, for each particular input bin, a weight multiplier that multiplies a vector comprising symbols allocated to subchannels corresponding to said input bin by a beneficial weighting matrix, elements of a result vector of said weight multiplier corresponding to different channel inputs of said plurality of channel inputs.

122. The apparatus of claim 121 wherein said beneficial weighting matrix comprises an input singular matrix of a matrix containing values representing characteristics of said channel, said channel coupling said plurality of channel inputs to one or more channel outputs.

123. The apparatus of claim 121 wherein said beneficial weighting matrix is obtained from a matrix containing values representing characteristics of a channel coupling said plurality of channel inputs to one or more channel outputs.

124. The apparatus of claim 121 wherein said beneficial weighting matrix is chosen to reduce interference to unintended receivers.

125. The apparatus of claim 124 wherein said beneficial weighting matrix is chosen based upon characterization of a desired signal subspace.

126. The apparatus of claim 125 wherein said beneficial weighting matrix is chosen further based upon characterization of an undesired signal subspace.

127. The apparatus of claim 126 wherein characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

128. The apparatus of claim 116 wherein said spatial processor operates so as to reduce interference radiated to unintended receivers.

129. The apparatus of claim 116 wherein said spatial processor, allocates symbols to each combination of channel input and input bin so that there is a one-to-one mapping between spatial direction of a particular subchannel to which a particular symbol has been allocated and channel input to which said particular symbol is allocated.

130. The apparatus of claim 116 further comprising a coder that applies a coding procedure to said symbols prior to processing by said spatial processor.

131. The apparatus of claim 130 wherein said coding procedure is applied independently for each of said subchannels.

132. The apparatus of claim 130 wherein said coding procedure is applied independently for each group of subchannels corresponding to an input bin of said substantially orthogonalizing procedure.

133. The apparatus of claim 130 wherein said coding procedure is applied independently for each group of subchannels corresponding to a particular spatial direction.

134. The apparatus of claim 130 wherein said coding procedure is applied integrally across all of said subchannels.

135. The apparatus of claim 130 wherein said coding procedure belongs to a group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding, trellis coding, turbo coding, and interleaving.

136. The apparatus of claim 130 wherein said coding procedure comprises a trellis coding procedure.

630  
631 137. The apparatus of claim 136 wherein a code design of said trellis coding  
632 procedure is based on one of: improved bit error performance in interference channels, a  
633 periodic product distance metric, exhaustive code polynomial search for favorable bit error  
634 rate polynomial searches, combined weighting of product distance and Euclidean distance,  
635 product distance of multiple Euclidean distances over short code segments or over a multi-  
636 dimensional symbol, and sum of product distances over short code segments.

637  
638 138. The apparatus of claim 136 wherein a code design of said trellis coding  
639 procedure is optimized for performance in a fading matrix channel.

640  
641 139. The apparatus of claim 130 wherein said coding procedure comprises a  
642 one-dimensional trellis coding procedure followed by an interleaving procedure with sequential  
643 groups of symbols output by said trellis coding having their internal order maintained by said  
644 interleaving procedure.

645  
646 140. The apparatus of claim 130 wherein said coding procedure comprises a  
647 multi-dimensional trellis coding procedure followed by an interleaving procedure with groups  
648 of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding  
649 procedure having their internal order maintained by said interleaving procedure.

650  
651 141. The apparatus of claim 130 wherein bit loading and power are allocated  
652 to each subchannel.

653  
654 142. The apparatus of claim 116 further comprising an ARQ system that  
655 retransmits symbols via at least one of said spatial processor, and said substantially  
656 orthogonalizing procedure processor upon receipt of a notification that said symbols to be  
657 retransmitted have been incorrectly received.  
658

143. The apparatus of claim 116 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a corresponding plurality of transmitter antenna elements

144. The apparatus of claim 142 wherein said plurality of transmitter antenna elements are co-located.

145. The apparatus of claim 144 wherein said plurality of transmitters are at disparate locations.

146. Apparatus of processing a sequence of symbols received via a plurality of outputs of a channel, said apparatus comprising:  
a substantially orthogonalizing procedure processor system that applies a receiver substantially orthogonalizing procedure to said sequence of symbols, said procedure being applied independently for each of said plurality of channel outputs, each output symbol of said substantially orthogonalizing procedure corresponding to a particular output bin and a particular one of said channel outputs; and  
a spatial processor that, for each output bin, spatially processes symbols corresponding to said output bin to develop spatially processed symbols assigned to a plurality of spatial directions, each combination of spatial direction and output bin specifying one of a plurality of subchannels.

147. The apparatus of claim 146 wherein said spatial processor operates to make said plurality of spatial directions into a set of orthogonal spatial dimensions.

148. The apparatus of claim 146 wherein said receiver substantially orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a wavelet transform, and processing through a plurality of bandpass filter/frequency converter pairs centered at spaced apart frequencies.

149. The apparatus of claim 146 further comprising: a cyclic prefix processor that applies a cyclic prefix removal procedure to said sequence of symbols independently for each of said channel outputs.

150. The apparatus of claim 146 wherein said receiver substantially orthogonalizing procedure is optimized to reduce deleterious effects of interference from undesired co-channel transmitters.

151. The apparatus of claim 146 wherein said spatial processor comprises, for each particular output bin, a weight multiplier that multiplies a vector comprising symbols of said output bin by a beneficial weighting matrix, elements of a result vector of said multiplier corresponding to different spatial directions.

152. The apparatus of claim 151 wherein said beneficial weighting matrix comprises an output singular vector of a matrix containing values representing characteristics of said channel, said channel coupling one or more channel inputs to said plurality of channel outputs.

153. The apparatus of claim 151 wherein said beneficial weighting matrix is chosen to minimize deleterious effects of interference from undesired transmitters.

154. The apparatus of claim 151 wherein said beneficial weighting matrix is chosen based upon characterization of a desired signal subspace.

155. The apparatus of claim 154 wherein said beneficial weighting matrix is chosen further based upon characterization of an undesired signal subspace.

156. The apparatus of claim 155 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.



157. The apparatus of claim 151 wherein said beneficial weighting matrix is obtained from a matrix containing values representing characteristics of said channel, said channel coupling one or more channel inputs and said plurality of channel outputs.

158. The apparatus of claim 157 wherein said beneficial weighting matrix is obtained by an MMSE procedure.

159. The apparatus of claim 146 further comprising: a decoder that applies a decoding procedure to said spatially processed symbols.

160. The apparatus of claim 159 wherein said decoding procedure is applied independently for each of said plurality of subchannels.

161. The apparatus of claim 159 wherein said decoding procedure is applied independently for each group of subchannels corresponding to an output bin of said substantially orthogonalizing procedure.

162. The apparatus of claim 159 wherein said decoding procedure is applied independently for each group of subchannels corresponding to a spatial direction.

163. The apparatus of claim 159 wherein said decoding procedure is applied integrally across all of said plurality of subchannels.

164. The apparatus of claim 159 wherein said decoding procedure belongs to a group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-interleaving.

165. The apparatus of claim 159 wherein said decoding procedure comprises a code sequence detection procedure to decode a trellis code, or convolutional code.

166. The apparatus of claim 165 wherein said code sequence detection procedure employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean metric, and Hamming metric.

167. The apparatus of claim 159 wherein said decoding procedure reduces deleterious effects of interference from undesired transmitters.

168. The apparatus of claim 146 further comprising:  
a system that sends a retransmission request when received symbols are determined to include errors.

169. The apparatus of claim 170 wherein said channel comprises a wireless channel and said plurality of channel outputs are coupled to a plurality of corresponding receiver antenna elements.

171. The apparatus of claim 170 wherein said plurality of receiver antenna elements are co-located.

172. The apparatus of claim 170 wherein said plurality of receiver antenna elements are at disparate locations.

173. In a digital communication system, apparatus for preparing a sequence of symbols for transmission via a plurality of inputs to a channel, said apparatus comprising:  
a substantially orthogonal procedure processor that applies a transmitter substantially orthogonalizing procedure to said sequence of symbols to develop a time domain symbol sequence; and  
a weight multiplier that multiplies at least one symbol of said time domain symbol sequence by a weighting vector selected for improved communication to develop a result vector, elements of said result vector corresponding to symbols to be transmitted via individual ones of said plurality of channel inputs.

782 174. The apparatus of claim 173 wherein said weighting vector comprises an  
783 element indicating delay to be applied for a particular one of said plurality of channel inputs.  
784

785 175. The apparatus of claim 174 wherein said weighting vector is optimized  
786 to reduce interference to unintended receivers.  
787

788 176. The apparatus of claim 173 wherein said weighting vector is chosen  
789 based upon characterization of a desired signal subspace.  
790

791 177. The apparatus of claim 176 wherein said weighting vector is chosen  
792 further based upon characterization of an undesired signal subspace.  
793

794 178. The apparatus of claim 177 wherein said characterizations of said desired  
795 signal subspace and said undesired signal subspace are averaged over at least one of time and  
796 frequency.  
797

798 179. The apparatus of claim 173 wherein said channel comprises a wireless  
799 channel and said plurality of channel inputs are associated with a  
800 plurality of transmitter antenna elements.  
801

802 ~~180.~~ 180. In a digital communication system, apparatus for processing a plurality  
803 of symbols received via a plurality of outputs of a channel, said apparatus comprising:  
804 a weight multiplier that performs a multiplication of an input vector whose  
805 elements correspond to symbols received substantially simultaneously via a selected one of said  
806 plurality of channel outputs by a weighting vector to obtain a time domain symbol  
807 corresponding to a particular input bin of a receiver substantially orthogonalizing procedure  
808 and that repeats said multiplication for successive received symbols to obtain time domain  
809 symbols corresponding to successive input bins of said receiver substantially orthogonalizing  
810 procedure; and

811 a substantial orthogonalizing procedure processor that applies said substantially  
812 orthogonalizing procedure processor to said obtained time domain symbols.

813  
814 181. The apparatus of claim 180 wherein said weighting vector comprises an  
815 element indicating delay to be applied for a particular one of said plurality of channel outputs.  
816

817 182. The apparatus of claim 180 wherein said weighting vector is optimized  
818 to reduce deleterious effects of interference from unintended transmitters.  
819

820 183. The apparatus of claim 180 wherein said weighting vector is chosen  
821 based upon characterization of a desired signal subspace.  
822

823 184. The apparatus of claim 183 wherein said weighting vector is chosen  
824 further based upon characterization of an undesired signal subspace.  
825

826 185. The apparatus of claim 184 wherein said characterizations of said desired  
827 signal subspace and said undesired signal subspace are averaged over at least one of frequency  
828 and time.  
829

830 186. The apparatus of claim 180 wherein said channel comprises a wireless  
831 channel and said plurality of channel outputs are associated with a plurality of corresponding  
832 receiver antenna elements.  
833

834 187. In a digital communication system, apparatus for preparing symbols for  
835 transmission via a plurality of inputs of a channel, said apparatus comprising:

836 a plurality of symbol inputs, each of said symbol inputs receiving a symbol  
837 intended for a particular input bin of a transmitter substantially orthogonalizing procedure so  
838 that each of a plurality of input bins of said transmitter substantially orthongonalizing  
839 procedure has an allocated symbol;

840 a spatial processor that, for each particular input bin of said plurality of input  
841 bins, spatially processes said symbol allocated to said particular input bin to develop a spatially  
842 processed symbol vector, each element of said spatially processed symbol vector being  
843 assigned to one of said channel inputs; and

a substantially orthogonalizing procedure processor that applies said substantially orthogonalizing procedure for a particular channel input, inputs to said substantially orthogonalizing procedure being for each input bin, a symbol of said processed symbol vector for said input bin corresponding to said particular channel input, and that applies said substantially orthogonalizing procedure for each of said plurality of channel inputs.

188. The apparatus of claim 187 further comprising:  
a cyclic prefix processor that applies a cyclic prefix processing procedure to outputs of said substantially orthogonalizing procedure independently for each particular channel input.

189. The apparatus of claim 187 wherein said substantially orthogonalizing procedure is optimized to reduce interference to unintended receivers.

190. The apparatus of claim 187 wherein said spatial processor comprises:  
a weight multiplier that multiplies said symbol allocated to said particular input bin by a beneficial weighting vector to obtain said spatially processed symbol vector.

191. The apparatus of claim 190 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling said plurality of channel inputs and one or more channel outputs.

192. The apparatus of claim 190 wherein said beneficial weighting vector is chosen to select a beneficial spatial direction for transmission.

193. The apparatus of claim 191 wherein said beneficial weighting vector is chosen to reduce interference to unintended receivers.

194. The apparatus of claim 193 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace

875           195. The apparatus of claim 194 wherein said beneficial weighting vector is  
876 chosen further based upon characterization of an undesired signal subspace.

878           196. The apparatus of claim 195 wherein said characterizations of said desired  
879 signal subspace and said undesired signal subspace are averaged over at least one of time and  
880 frequency.

882           197. The apparatus of claim 187 wherein said channel comprises a wireless  
883 channel and said plurality of channel inputs are associated with a corresponding plurality of  
884 transmitter antenna elements.

886           198. In a digital communication system, apparatus for processing symbols  
887 received by a plurality of outputs of a channel comprising:

888           a substantially orthogonalizing procedure processor that applies a receiver  
889 substantially orthogonalizing procedure to symbols received via a particular one of said  
890 channel outputs and that said applies said receiver substantially orthogonalizing procedure for  
891 each of said channel outputs to develop a result vector for each of a plurality of output bins of  
892 said substantially orthogonalizing procedure, said result vector including a result symbol for  
893 each of said channel outputs; and

894           a spatial processor that, for each particular output bin of said substantially  
895 orthogonalizing procedure, spatially processes said result vector for said particular output bin  
896 to develop a spatially processed result symbol for said particular output bin.

898           199. The apparatus of claim 198 further comprising: a cyclic prefix removal  
899 processor that applies a cyclic prefix removal procedure to symbols independently for each of  
900 said channel outputs.

902           200. The apparatus of claim 198 wherein said substantially orthogonalizing  
903 procedure is optimized to reduce deleterious effects of interference from unintended  
904 transmitters.

905

906           201. The apparatus of claim 198 wherein said spatially processor comprises a  
907 weight multiplier that multiplies a beneficial weighting vector by said result vector to obtain  
908 said spatially processed result symbol.

909  
910           202. The apparatus of claim 201 wherein said beneficial weighting vector is  
911 an input singular vector of a matrix storing values indicative of characteristics of said channel,  
912 said channel coupling one or more channel inputs and said plurality of channel outputs.

913  
914           203. The apparatus of claim 201 wherein said beneficial weighting vector is  
915 chosen to select a particular spatial direction for reception.

916  
917           204. The apparatus of claim 203 wherein said beneficial weighting vector is  
918 chosen to minimize deleterious effects of interference from unintended transmitters.

919  
920           205. The apparatus of claim 204 wherein said beneficial weighting vector is  
921 chosen based upon characterization of a desired signal subspace.

922  
923           206. The apparatus of claim 205 wherein said beneficial weighting vector is  
924 chosen based upon characterization of an undesired signal subspace.

925  
926           207. The apparatus of claim 206 wherein said characterizations of said desired  
927 signal subspace and said undesired signal subspace are averaged over at least one of time and  
928 frequency.

929  
930           208. The apparatus of claim 198 wherein said channel comprises a wireless  
931 channel and said plurality of channel outputs are associated with a corresponding plurality of  
932 channel outputs.

933  
934           209. In a digital communication system including a communication channel  
935 having one or more inputs and at least one or more outputs apparatus for determining

characteristics of said channel based on signals received by said one or more outputs,  
comprising:

a receiver system receiving via said one or more channel outputs, at least  
training symbols transmitted via a particular spatial direction of said channel, being an extent  
in symbol periods of a duration of significant terms of an impulse response of a channel;

a substantially orthogonalizing procedure processor that applies a substantially  
orthogonalizing procedure processor to said received at least training symbols to obtain a  
time domain response for said particular spatial direction; and

an inverse substantially orthogonalizing procedure processor that applies an  
inverse of said substantially orthogonalizing procedure to a zero-padded version of said time  
domain response to obtain a frequency response for said particular spatial direction.

210. The apparatus of claim 209 wherein said substantially orthogonalizing  
procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially  
orthogonalizing procedure comprises a Fast Fourier Transform.

211. The apparatus of claim 209 wherein said receiver system receives exactly  
training symbols.

212. The apparatus of claim 209 wherein said receiver system, said  
substantially orthogonalizing procedure processor and said inverse substantially  
orthogonalizing procedure process operate repeatedly for a plurality of spatial directions.

213. The apparatus of claim 209 wherein each of said plurality of spatial  
directions corresponds to transmission through one of said plurality of channel inputs  
exclusively.

214. The apparatus of claim 209 wherein said training symbols belong to a  
burst of N symbols and said characteristics are determined for said burst.



966 215. The apparatus of claim 214 said receiver system, said substantially  
967 orthogonalizing procedure processor and said inverse substantially orthogonalizing procedure  
968 process operate repeatedly for a plurality of bursts.

969  
970 216. The apparatus of claim 215 further comprising:  
971 means for smoothing said time-domain response over successive bursts.

972  
973 217. The apparatus of claim 216 wherein said smoothing means comprises:  
974 means for Kalman filtering said time-domain response over successive bursts.

975  
976 218. The apparatus of claim 217 wherein said smoothing means comprises  
977 means for Wiener filtering said time-domain response over successive bursts.

978  
979 219. The apparatus of claim 209 wherein said communication channel  
980 comprises known and unknown components, wherein said effects of said known components  
981 are removed by deconvolution, and characteristics of said unknown components are  
982 determined by said a), b), c), and d) steps, thereby reducing .

983  
984 220. In a digital communication system including a communication channel  
985 having one or more inputs and one or more outputs, apparatus for determining characteristics  
986 of said channel based on signals received via one or more channel outputs, comprising:  
987 a receiver that receives training symbols via said channel outputs; and  
988 a processor that computes characteristics of said channel based on said received  
989 training symbols and assumptions that an impulse response of said channel is substantially  
990 time-limited and that variation of said impulse response over time is continuous.

991  
992 221. In a digital communication system, apparatus for communicating over a  
993 channel having at least one input and at least one output, and having a plurality of either inputs  
994 or outputs, said apparatus comprising:

means for dividing said channel into a plurality of subchannels, each subchannel corresponding to a combination of spatial direction and an input bin of a substantially orthogonalizing procedure; and

means for communicating symbols over one or more of said plurality of subchannels.

222. In a digital communication system, apparatus for preparing a sequence of symbols for transmission via a plurality of inputs of a channel, said apparatus comprising:

a plurality of parallel subchannel inputs that receive said sequence of symbols, said subchannel inputs corresponding to a plurality of subchannels, each subchannel corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a channel input; and

a substantially orthogonalizing procedure processor that applies, independently for each said channel input, said transmitter substantially orthogonalizing procedure to said symbols assigned to each said channel input.

223. Apparatus for processing a sequence of symbols received via a plurality of outputs of a channel, said apparatus comprising the steps of:

a substantially orthogonalizing procedure processor that applies a receiver substantially orthogonalizing procedure to said sequence of symbols, said procedure being applied independently for each of said plurality of channel outputs, each output symbol of said receiver substantially orthogonalizing procedure corresponding to a subchannel identified by a combination of a particular output bin and a particular one of said channel outputs; and

a processor that processes symbols in said subchannels.

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